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ASSESMENT OF OPERATING CHARACTERISTICS OF FUELS FOR DIESEL ENGINES

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Summary. The present paper deals with main problems occurring when supplying combustion engines with liquid fuels. Disadvantageous effects occurring in fuel supply systems of engines were discussed, and possible problems connected with reduction of emission of noxious matters were presented. Test procedures were elaborated at the Institute of Vehicles of the Warsaw University of Technology, for an assessment of the characteristics of liquid fuels in connection with pollution of fuel sprayers and emission of noxious matters. Results of tests of assessed fuels were presented, including vegetable originated fuels.

Key words: fuel supply system, fuel sprayers, pollution

INTRODUCTION

The significant progress in the technology of gasoline and fuel oils has definitely enhanced their quality, which can be measured with constantly decreasing operating troubles of engine users, and constantly decreasing impact of combustion on natural environment of man. A touchstone of said progress in production technology of fuel oils may be the elaboration of a production method of low-sulfur light fuel oils, containing multi-purpose packs of improving additives. In recent years, the use of vegetable matters in composition of fuels has become the object of legislative initiatives in member countries of the European Community, also in Poland.

The European Commission has defined three potential areas for alternative fuels, based on renewable energy sources, which could reach 6–7% until 2010, and up to 20% in 2020 [Wiśniewski and Rogulska]. The first concerns the use of, within the next few years, liquid biofuels and pyrolytic oils, and the other two areas of alternative fuels concern the use of natural gas (middle-term perspective), and hydrogen (long-term perspective).

VEGETABLE-ORIGINATED COMPONENTS OF LIQUID FUELS

Since a few dozen of years attempts have been made, stimulated mainly by ecological and social reasons, and supported by political actions, to introduce on a larger scale biofuels, mainly as components of petroleum originated fuels. In Polish conditions, such a component of fuel oils could be the methyl ester of rape oil fatty acids (EMKOR), which in combination with the pack of improving additives could be used as biodiesel.

Esters of rape oils can be used even as self-contained fuel, but in this case one can observe reduced engine power and increased fuel consumption.

The problem connected with the use of vegetable originated components consists (economical reasons excepted) mainly in solving problems connected with:

- production of vegetable components, meeting unified technological requirements,
- composition, storage and distribution of fuels,
- fulfillment of requirements concerning the quality of fuels containing vegetable components as stated in Polish Standards, defining technical and operating characteristics of petrol (gasoline) and fuel oils,
- consent of vehicle manufacturers to use such fuels (users fear to lose manufacturer's guarantee on engine elements as a result of using fuels not accepted by vehicle manufacturer).

As far as the impact of such fuels on functioning of a diesel engine and on its emission is concerned, the following results of their use, advantageous and disadvantageous, can be mentioned [Chłopek *et al.* 1996, Merkisz 1999, Szlachta 2002]:

- growth of microorganisms can be observed, in fuel supply system of the engine, and especially in fuel tank, where often sediments appear for not fully explained reasons,
- esters (fatty acids) can be corrosive to rubbers and plastics, and they can cause accelerated corrosion of metal elements of fuel supply system,
- increased cooking (pollution with carbon deposits) of injection sprayers can take place,
- increased viscosity of esters at low ambient temperatures can cause difficult engine start-up and operation,
- increase of lubricating characteristics of fuel (esters) has a positive influence on the life of frictional couples in fuel supply system, and makes possible further reduction of sulfur contents and elaboration of lighter fuels,
- in general, an advantageous reduction of CO, HC and PM is observed,
- in general, there is an increase of NO_x emission, and as there are no effective means of limiting such an emission in diesel engines, this phenomenon is especially disadvantageous,
- increased formation rate of aldehydes in combustion chamber is observed (due to their highly detrimental impact on natural environment, in the next few years possible limitation on their emission has to be taken into account),
- increased concentration of aldehydes before catalytic reactor should not significantly influence their emission to the atmosphere (highly reactive compounds are easily oxidized),
- combustion of esters definitely reduces PM emission; moreover, absence of sulfur in esters in combination with low PM emission has a positive influence on functioning of oxidizing reactors and particulate solids filters,
- due to their biodegradability, esters are not very harmful to the environment,

– during long-lasting operation, dilution of lubricating oil with fuel can arise, as well as precipitation of deposits, and loss of oil properties.

Undoubted and unquestionable advantage of using such a type of fuels is that they are renewable fuels, and they contribute to the reduction of the concentration of carbon dioxide in the atmosphere (greenhouse gas) due to short (1 year) process of carbon circulation in the atmosphere. Another significant argument for using vegetable fuel is that they are practically free of sulfur compounds, reducing their emission to the atmosphere and at the same time making easier the functioning of exhaust gas purification systems (catalytic reactors, particulate solids filters)

Contemporary combustion engines require high quality fuel. The basic fuel (base fuel) meets the requirements of engines in unsatisfactory manner, causing several disadvantageous effects, in general located in engine fuel supply system. For this reason, adequate regulations impose on fuel manufacturers the obligation to use properly selected packs of improving additives. Said packs include detergents increasing the cleanness of fuel supply system, as well as anti-corrosives and anti-oxidants. In fuel oils additives increasing cetane number and reducing smoke emission are used, as well as demulsifiers and anti-foaming agents, and so called depressants making engine cold start-up easier. Improperly selected packs of improving additives (disadvantageous chemical composition, too low or too high concentration), and high contents of sulfur compounds in fuel can decrease engine efficiency and reduce the life of exhaust gas purification systems. Fuels containing vegetable originated components can intensify some negative effects or processes occurring within the combustion engine, and for this reason they will require the selection of properly modified and supplemented pack of additives.

Pollution of injection sprayers in diesel engines is one of the most frequently met effects connected with fuel characteristics, especially of vegetable originated fuels, said effect being confirmed by tests carried out on engines or complete vehicles [Kruczyński 2004].

POLLUTION OF INJECTION SPRAYERS IN DIESEL ENGINES

One of undesirable features of fuel for diesel engines is its tendency to pollute injection sprayers. In engine-related literature this effect is called „cooking of fuel" in injection sprayer, and most often occurs in engines with precombustion chambers, and in case of supplying engines with heavy fuels. In general, the temperature in a sprayed injection does not exceed the temperature of fuel cooking. However, often as a result of engine malfunction or malfunction of fuel supply system itself, said temperature considerably increases, leading to local decomposition of fuel with release of its components. The result of this effect is the clogging of holes in sprayers, and also depositing of cooking products in form of pitch deposits (so called sealing wax) on the surface of closing cones, and on the surface of sprayed needle and body. Often the result of wax depositing on guiding surface is loss of freedom of needle movements, or so called hanging-up of sprayer needle. The adherence of said deposits to any substrate is very high, and their removal requires mechanical operations, which in turn requires disassembly and cleaning, or even replacement of said parts. The external effect of excessive waxing of sprayer is loss of power and increase of fuel consumption by the engine in use. Additionally, emission of carbon dioxide and hydrocarbons is observed, as well as considerable increase of smoke emission and the resulting emission increase of particulate matter.

The final assessment in European conditions, from the point of view of emission assessment of noxious matters to the atmosphere and fuel consumption, should be the tests carried out according to European homologation procedures, on properly selected model vehicles and engines, according to the following procedures:

- vehicle testing in NEDC (New European Drive Cycle) drive cycle,
- engine testing in ESC (European Stationary Cycle) test or ECE R49 test,
- engine testing in non-stationary test - ETC (European Transient Cycle),
- in which tests typical fuel consumption and emission are assessed:
- carbon dioxide – CO,
- sum of hydrocarbons – HC,
- nitric oxides – NO_X,
- particulate matter – PM.

These measurements can be, depending on actual needs, complemented with specialist chemical analyses in order to determine contents of individual hydrocarbons or their groups in exhaust gas, or possibly the contents of other compounds selected for the test purposes, using gas chromatography or other methods of physical chemistry.

TEST PROCEDURE

A procedure for testing fuels was elaborated at the Institute of Vehicles of the Warsaw University of Technology, said procedure being carried out on Peugeot XUD9 model engine, assessing the influence of fuel on:

- pollution of injection sprayers,
- emission of noxious matters.

Test of pollution of injection sprayers

This test is carried out according to CEC PF-023 procedure [ISO 17025, Interpretation Document], lasts 10 hours and includes measurements of pollution of injection sprayers according ISO 4010 procedure. Test procedure is as follows:

- measurement of air flow rate as function of needle lift in new sprayers according to ISO 4010, on test stand according to schematic Fig. 1,
- fitting of sprayers to the engine and test of Peugeot XUD 9 engine under steady conditions ($M_e = 58 \pm 2$ Nm, $n = 3000 \pm 15$ RPM) for 10 hours at pressure of opening start of fuel injector reduced to $11,5 \pm 0,5$ MPa,
- removal of sprayers and measurement of air flow rate through polluted sprayers,
- assessment of pollution level of sprayers on the basis of relative decrease of air flow for needle lift equal to 0.1 mm.

Test of emission of noxious matters

This test is carried out according to standard, well-known test cycle according to ECE procedure, Regulations No. 49 [Merkisz 1999], defining unitary emission of CO, HC, NO_X, and PM.

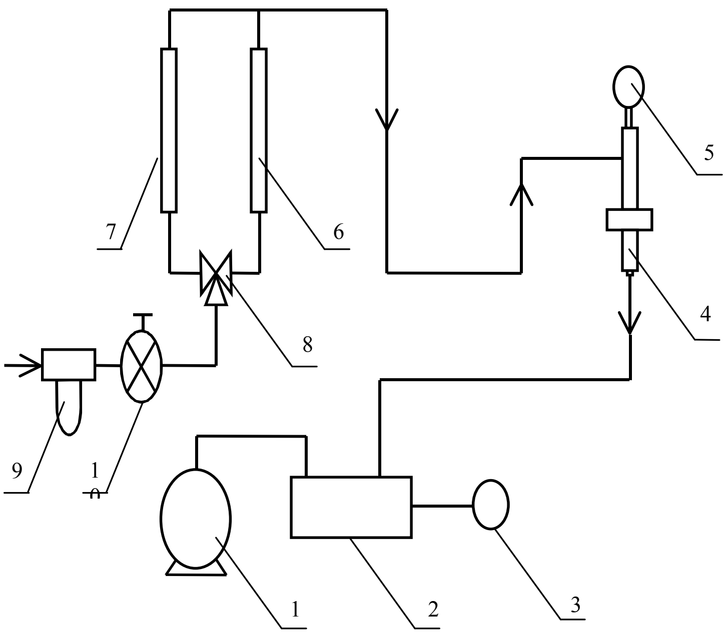

Fig. 1 . Block diagram of test stand for measuring air flow rate through sprayers according to ISO 4010 Symbols: 1 – vacuum pump, 2 – vacuum tank, 3 – negative pressure indicator, 4 – sprayer under test, 5 – sprayer needle lift meter, 6, 7 – air flow rate meters with different measuring ranges, 8 – two-way valve, 9 air filter, 10 – pressure controller

TEST RESULTS

Tests according to above described procedures were carried out for the following fuels:

– basic fuel oil,
– fuel oil with pack of improving additives,
– high viscosity EMKOR,
– low viscosity EMKOR.

Test results will be presented in the following order:

Test of pollution of injection sprayers

In Figures 2 and 3 examples of measurements are shown, i.e. measurements of air flow rate for four new sprayers (Fig. 2), and for the same sprayers polluted during 10 hours test when supplying Peugeot XUD 9 engine with fuel oil with pack of improving additives. Fig. 4 illustrates calculation results of averages, from four cylinders of test engine, of air flow rate through new sprayers and sprayers polluted during 10 hours test when supplying XUD 9 engine with tested fuels as follows: A – basic fuel oil, B – fuel oil with pack of improving additives, C – high viscosity EMKOR, D – low viscosity EMKOR.

Fig. 5. illustrates calculation results of relative reduction of air flow for needle lift equal to 0.1 mm when supplying the engine with tested fuels.

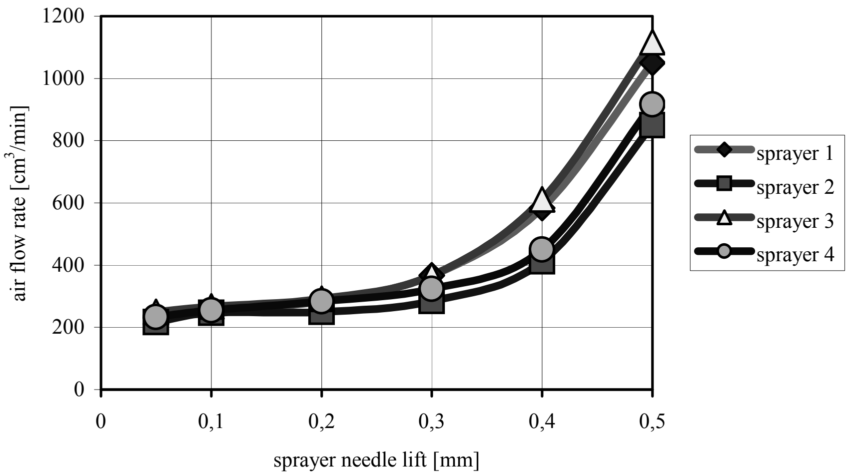

Fig. 2. Air flow rate as function of injection sprayer needle lift before CEC PF-023 test

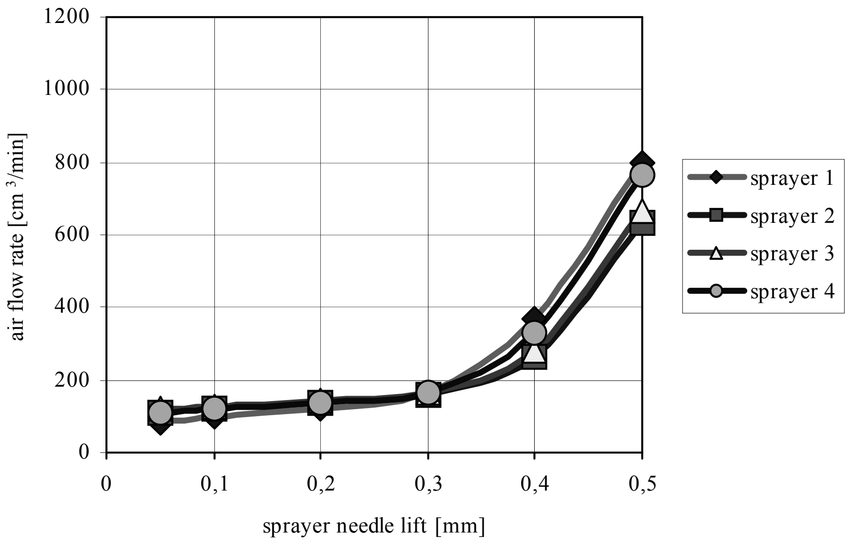

Fig. 3. Air flow rate as function of needle lift after CEC PF-023 test – fuel oil with pack of improving additives

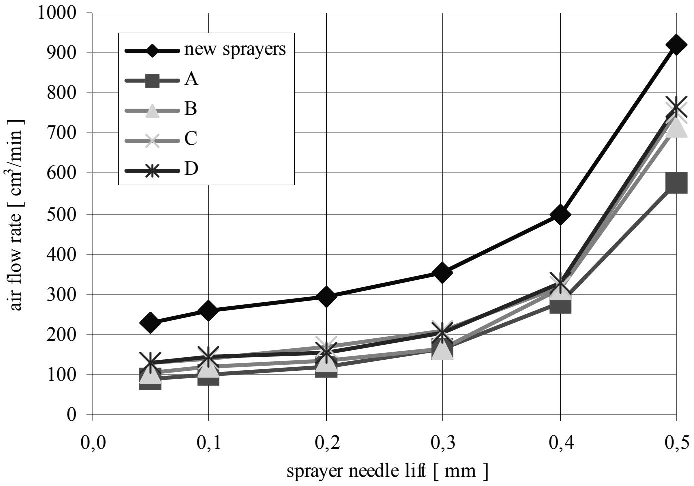

Fig. 4. Average value of air flow rate for four sprayers
Symbols: A – basic fuel oil, B – fuel oil with pack of improving additives, C – high viscosity EMKOR, D – low viscosity EMKOR

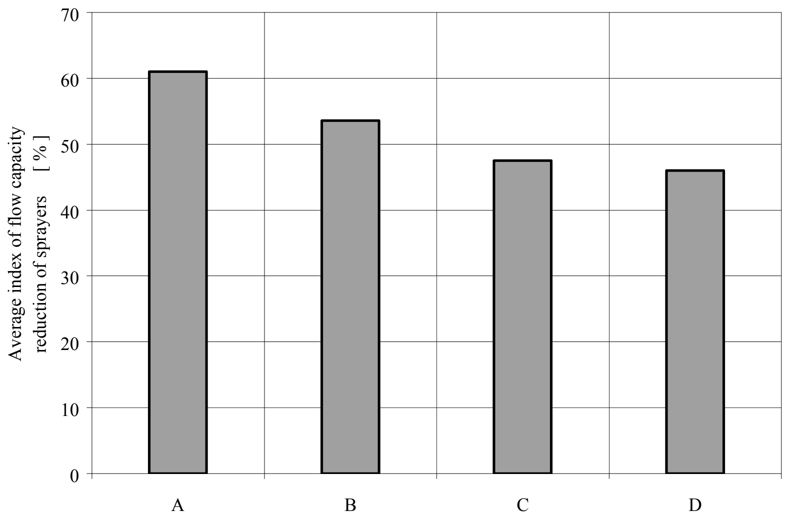

Fig. 5. Average index of flow capacity reduction of sprayers (for four sprayers)
Symbols: A – basic fuel oil, B – fuel oil with pack of improving additives, C – high viscosity EMKOR, D – low viscosity EMKOR

Test of emission of noxious matters

Fig. 6 illustrates measurement results of unitary emission of carbon monoxide (CO), sum of hydrocarbons converted into propane (HC), nitric oxides (NO_X), and particulate matter (PM) in stationary ECE Regulations No. 24 test of Peugeot XUD 9 engine supplied with tested fuels. Tests were carried out on new fuel sprayers, using standard pressure of opening start of injectors as recommended by the engine manufacturer.

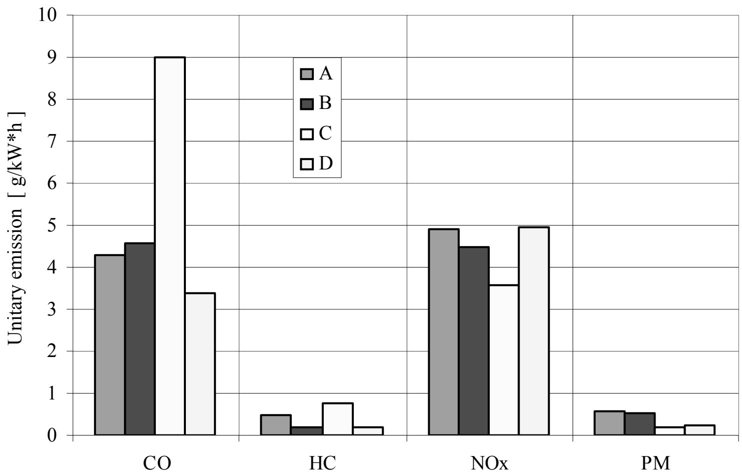

Fig. 6. Unitary emission of carbon monoxide, hydrocarbons, nitric oxides and particulate matters in ECE R49 test.

Symbols: A – basic fuel oil, B – fuel oil with pack of improving additives
C – high viscosity EMKOR, D – low viscosity EMKOR

CONCLUSIONS

1. The elaborated test procedure makes it possible to assess fuel influence on pollution of injection sprayers and emission of basic noxious matters, clearly differentiating fuels under test.
2. The pack of improving additives used in combination with the basic mineral fuel oil clearly reduces the pollution of injection sprayers without any substantial influence on emission of noxious matters.
3. Supplying the engine with pure esters of rape oil causes the pollution of injection sprayers at pollution level obtained when adding improving additive to basic mineral oil.
4. Emission of noxious matters when supplying the engine with pure esters of rape oil clearly depends on viscosity of esters. High viscosity results in visible increase of emission of carbon monoxide and hydrocarbons without any substantial influence on the emission of nitric oxides. Emission of particulate matter is always lower, and amounts approximately to 50% of mineral oils emission.

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